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High frequency spraying device

This invention relates generally to a high frequency spraying device suitable for atomising a coating fluid, which device is equipped with a drying device for drying and/or cross-linking the coating fluid applied to the body to be coated by means of the high frequency spraying device, wherein the device also has a substrate support which is suitable for retaining the body to be coated firmly in a position suitable for coating during the coating process. In particular, this invention relates to such a high frequency atomising device which does not atomise the coating fluid by means of a pressure loaded nozzle but which atomises the coating fluid without force and without air induction by means of a resonance body that can be excited to produce high frequency vibrations, forming a spray mist. According to the invention such devices are also included in which a movement of the substrate and/or the atomising device takes place for the coating process.

The high frequency vibrations produced by the excitation of the resonance body may, for example, be generated in an electromechanical converter by means of piezoceramic elements which have been excited to produce electrical vibrations. These mechanical vibrations produced by means of the piezoceramic elements may then, when amplified, be fed to the resonance body. With these mechanical high frequency vibrations a coating fluid film applied continuously to the resonance body can be excited to form capillary waves so that fine droplets on the vibration cavities forming on the capillary wave are cut off, as a result of which an atomisation or spray mist is formed.

Possible applications for such a pressure-less high frequency atomising device may be found, for example, in the fields of air or product moistening, microelectronics, medical engineering, etc. Further, such pressure-less high frequency atomising devices may prove very suitable for the gassing or degassing of fluids. Similarly, the high frequency atomising devices mentioned may be suitable for the use as separating means and/or for the delivery of fluids in filling and mixing processes.

However, particular importance is attached to these high frequency atomising devices in the field of medical engineering, for example for coating mechanical implants, for example bone and joint screws, heart valve prostheses and filigree substrates, particularly vascular supports, such as stents for instance, thinly and homogeneously with a coating fluid. For instance, closed coat thicknesses of approx. 1 nm to approx. 1 mm, if necessary even more, can be achieved with the device according to the invention. Preferred coat thicknesses range from 1 nm to 100 µm, and in particular preference from 1 nm to 10 µm, e.g. 1 nm to 1 µm or 10 nm to 1 µm, and in particular preference from 1 nm to 10 nm.

Such stents are required, for example, to protect the coronary artery of a cardiac infarction patent, widened by means of a balloon dilation, permanently from renewed occlusion. In order to protect the coronary artery permanently from renewed occlusion, such stents, which assume, for example, the shape of a hollow cylindrical wire netting in the nature of a lattice gate, comparable to a hair curler, are fitted into the coronary vessel, thus preventing renewed occlusion of the vessel or allowing at least its temporary postponement in many cases.

To ensure that these stents, like other medical implants or other bodies to be coated, which are referred to collectively in the following as substrates, are not rejected by the human organism, it is necessary to provide these substrates with a suitable coating which is not rejected by the human or animal body. To coat these substrates, which are often very fine and filigree in nature, the high frequency atomising device previously mentioned may be used in preference, for example.

An atomising device which is suitable for atomising coating fluid, without force or air induction, is disclosed, for example, in US patent no. 4,655,393. The ultrasonic atomiser disclosed in this patent consists essentially of two tubes connected to each other by means of a flanged connection in the longitudinal direction, wherein a drive element is inserted between the two adjacent flanges of both tubes, in order to excite the atomising unit to generate vibrations in the ultrasonic range. A feed hose is connected to the back of the ultrasonic atomiser for feeding the atomising device with coating fluid. On the front of the atomiser all the tubes on the front is reduced in its diameter to enable a further solid tube section with a smaller diameter to be formed. This further tube section widens in its cross-section, in the direction of the front of the atomising device, viewed along a circular trajectory, and terminates in a flat atomiser tip.

The flat atomiser tip and the inner cavity of the front tubes of the atomising device are connected by a plurality of thin rectilinear capillary tubes in order to load the atomiser tip with a coating means that is excited to generate high frequency vibrations. However, these fine tubes terminate obtusely and without any continuous process in the flat tip of the atomising device. Nevertheless, the continuous transition between the tubes and the flat tip results in an irregular

spray pattern during the operation of this atomising device, and in particular in an irregular droplet size in the spray mist produced. In particular, drops of larger diameter are also formed as a result of this discontinuous transition, which drops accumulate initially on the tip of the atomising device and become detached from the atomiser tip due to the action of the force of gravity when they reach a certain size. This is one reason, among others, why the atomising device disclosed in US 4,655,393 should only be used in vertical alignment with an upward pointing spray tip or in horizontal alignment. However, where the substrate to be coated is to be arranged underneath this atomising device, or even in the case of very thin, uniform coatings, it is frequently the case that larger drops become detached from the spray tip and drip onto the substrate, thereby rendering it useless for further application.

Another problem associated with the coating of substrates consists in the fact that such substrates are normally coated initially in a first stage in which they are retained by a first substrate holder so that they can be coated by means of a spraying device. However, the substrate must then normally be removed from this first substrate older so that it can be inserted in a drying oven for drying and/or hardening, for example. But this removal from the substrate holder proves problematic because when the substrate is removed from the first substrate holder the freshly applied, not yet set coating film can easily be damaged, as a result of which the substrate would also be rendered unusable for further application.

A further problem encountered when coating substrates with a high frequency atomising device such as that disclosed in US 4,655,393, for example, consists in the fact that the spray

mist produced by such an atomising device can only be modulated by the coating fluid supplied per unit of time of the atomising device and by the excitation frequency. However, it is not possible to influence the spraying characteristic further, e.g. for widening or narrowing the spray jet or for accelerating the spray mist by giving it a certain direction.

In the light of the problems described above, which may be encountered when coating a substrate with a high frequency atomising device, for example, the object of this invention is therefore to make available an improved high frequency atomising device for coating filigree substrates, which device does not suffer from the disadvantage of the formation of drops, so that it can also be operated with a downwardly directed resonance body. Furthermore, the aforementioned problem caused when the substrates are removed from the substrate holder, in order to be able to insert them in a drying oven for hardening, for example, will also be solved with this invention. Moreover, a high frequency atomising device will be supplied which enables the spray jet to be influenced not only by setting the coating fluid flow rate and the atomiser frequency, but also enables the spray jet to be accelerated or the spray cone to be widened or reduced.

According to a first aspect of this invention, these objects are achieved and problems solved for the first time with a high frequency atomising device for atomising a coating fluid and coating a substrate which has an atomising unit which can be excite to produce high frequency vibrations, which unit atomises the coating fluid fed to it to form a spray mist, and which is also equipped with a positionable substrate holder which retains the substrate to be coated in a position favourable for coating inside the spray mist produced by the high frequency atomising device throughout the atomising and

coating process, thus enabling the substrate to be wetted uniformly with the spray mist produced and thin, homogeneous coats to be applied.

According to an alternative embodiment the entire atomising unit can also be moved along a substrate, or a movably arranged substrate can be provided with a movably arranged atomising unit.

In order to counteract the problem already described, which occurs when the freshly coated substrates are removed, the high frequency atomising device also has a heat source which is suitable for drying the spray mist coat formed on the substrate without having to remove the substrate from the substrate holder. This therefore affords the advantage, which can be achieved with this invention, that the freshly coated substrate need not be removed from the substrate holder for drying, thereby obviating the risk of damaging the freshly coating substrate or the freshly applied coating film.

As already explained, the atomising unit incorporates an ultrasonic atomiser which is suitable for atomising a coating fluid fed to the atomising unit into a fine spray mist. To produce the high frequency ultrasonic waves, the ultrasonic atomiser is provided, for example, with a piezoceramic element which converts electric weaves to mechanical waves, whereby a coating fluid fed without pressure to the ultrasonic atomiser forms capillary waves from whose vibration cavities very fine droplets are detached. In order to feed the coating fluid as uniformly and continuously as possible to the atomiser tip of the atomising unit, from which the coating fluid excited to generate vibrations is sprayed down, the atomising unit is provided with a resonance body which widens into the shape of a trumpet. This capillary type resonance body widening into

the shape of a trumpet vibrates together with the ultrasonic atomiser in the excited frequency, so that the coating fluid fed to the resonance body also vibrates in the excited frequency on the surface of the resonance body and forms the capillary waves already mentioned.

In order to supply the resonance body that widens into the shape of a trumpet uniformly and continuously with coating fluid, the resonance body widening into the shape of a trumpet is connected to a capillary tube by which the inner face of the resonance body is supplied with coating fluid. To ensure that there are no discontinuities from the escape of the coating fluid from the capillary tube and during the transition to the inner face of the resonance body, the capillary tube is incorporated in a nozzle of the resonance body widening into the shape of a trumpet so that the end of the capillary tube passes into the resonance body without jumps or steps. When the coating fluid escapes from the capillary tube it is therefore distributed on the inner face of the resonance body in a thin film, which inner face widens concentrically into the shape of a trumpet.

According to a preferred embodiment the resonance body that widens into the shape of a trumpet may be designed in the shape of a horn which widens, for example, viewed in cross-section, to perform a tractrix function, an exponential function or a clotoid function, to mention but a few. To increase the atomising area of the resonance body, a funnel-shaped section, for example, can be connected to the horn of the resonance body described above. It is also possible to widen the horn of the resonance body to such an extent that the radius of curvature of the horn is parallel with the capillary tube incorporated in the resonance body. In this case the horn could be continued outwards at its outer opening

in a perforated disc whose single hole then coincides with the horn opening. One advantage that can be achieved by such an enlargement of the resonance body may consist in the fact that the entire quantity of coating fluid fed to the resonance body via the capillary tube is atomised. Due to the enlargement of the resonance body it can therefore be ensured that no non-atomised residues of the coating fluid accumulate on the resonance body that would otherwise drop down without being atomised onto one edge of the resonance body due to gravity.

Furthermore, to avoid the detachment of large coating fluid drips on the resonance body, or differences in the coat thickness of the coating fluid film formed on the inner face of the horn, the resonance body which, as stated previously, passes into a circular perforated disc, is ideally loaded with coating fluid by means of a controllable, pulsation-free proportioning pump. Although proportioning quantities of 0.1 to 100 ml/min, and preferably 0.5 ml/min., prove advantageous for the use of the high frequency atomising device mentioned previously in connection with the medical engineering field, the high frequency atomising device can of course be operated with other proportioning quantities where volumetric flows of up to 50 l per hour can be achieved without difficulty, or where smaller volumetric flows of the order of 1 µl/min., for example, can be achieved.

To obtain the best possible spray pattern without detachment of undesirable drops, the individual dimensions of the device according to the invention are matched to each other, also taking into consideration the volumetric flow of the coating means and its viscosity. For the usual applications in the medical field it has normally proved appropriate to select the inside diameter of the capillary tube ranging from 0.01 to 15 mm. For the conventional coating fluids suitable for coating

medical substrates the diameter of the capillary tube should preferably be chosen within the range of 0.3. mm to 0.5 mm, but preferably approximately 0.4 mm. The diameter of the expanding resonance body must be matched correspondingly, and here diameters of between 3 and 30 mm have proved suitable as the diameter of the perforated disc previously described. In the field of medical engineering, however, diameters for the perforated disc ranging between 3 and 30 mm, and preferably of the order of 8 mm, have proved advantageous.

To set the spray pattern of the high frequency atomising device according to the invention, the spray mist produced can be modulated with a controllable air or inert gas jet, the inert gas jet at the same time providing the explosion protection of the device. The air or inert gas jet for modulating the spray pattern is produced by enclosing the entire atomising unit, including the ultrasonic atomiser, with a housing that is open on one side, which housing has a connection for a controllable inert gas supply, and obviously a connection for the coating fluid, so that the inert gas supplied to the inside of the housing via the inert gas connection of the housing is able to escape focussed in the manner of a jet at one opening of the housing, as a result of which the inert gas jet required for modulating the spray pattern is generated

By arranging the resonance body of the ultrasonic atomiser either immediately in one opening of the housing or in the approximate area of the housing opening, the spray pattern of the high frequency atomising device can be modulated by the inert gas jet produced. The natural volumetric flow of the spray mist can, for example, be accelerated by controlling the inert gas supply. Furthermore, the spray jet can be directed and stabilised by the inert gas jet produced, also enabling

the widening of the spray cone to be adjusted. Because of the inert gas support, the spray cone of the atomised coating material can be varied from 0 to 180°, preference being given to spray jet cones with an angle of approximately 30° for smaller components, for example the substrates to be found in the field of medical engineering.

In order to be able to influence the spray jet characteristic more effectively one of the openings of the housing may be provided with an inert gas nozzle through which the inert gas supplied via the inert gas feed escapes as a carrier medium for spray jet conditioning of the spray mist. This nozzle may, for example, be designed as an expanding funnel which expands outwards or reduces from the housing opening. An annular gap, through which the inert gas fed to the inside of the housing is able to escape, is formed between the funnel and resonance body by the resonance body of the ultrasonic atomiser arranged in this expanding or reducing funnel. The width of this annular gap may, for example, be varied by moving the resonance body in the longitudinal direction of the funnel, or by varying the angle of expansion of the funnel, enabling the spray jet characteristic to be further influenced.

In contrast to pressurised spray nozzles of prior art, the characteristic of the spray jet generated can therefore be influenced in several different ways. For example, the spray jet may be varied not only by the variations in the volumetric flow of the coating fluid, but also by adjusting the working frequency of the atomising unit in the ultrasonic range between 20 kHz to 3 MHz, preferably 20 to 200 kHz. A further possibility of varying the spray jet characteristic also consists in varying the energy supply to the atomising unit, which normally ranges from approximately 0.01 to 100 W. A fourth possibility of varying the spray jet consists, as

already described, in influence the spray jet by adjusting the inert gas supply to the housing in which the atomising unit is installed. A further possibility of influencing the spray jet characteristic consists, as already discussed, in influencing the spray jet by varying the annular gap formed between the resonance body and the funnel expanding in the connection to one of the housing openings.

Here there are also possibilities that are already known from paint spraying technology e.g. dilution, selection of solvents, removal of the nozzle from the substrate, additives, for optimising the spray pattern.

There is also a possibility of carrying out extensive coatings in which a plurality of nozzles can be arranged next to each other in cascade fashion. Here the extensive substrate can be guided past the nozzles by means of a conveyor belt, or the nozzles can be guided above the standing substrate.

It may also be preferable to provide the high frequency atomising device with one or more devices, or to provide such devices on it, which generally allow adjustment of the temperature of the inert gas and/or of the coating fluid and/or of the coating chamber, for example a controlled or uncontrolled device for tempering the inertised air in the application system, in which case the following principles of action may be applied: heat exchanger process in the apparatus for cooling or heating the ultrasonic nozzle, the inertising gas or the coating solutions, or any combination thereof.

This means that it may be advantageous, in a coating process or when coating a substrate with a coating fluid, for constant, homogeneous and constant conditions to prevail for the coating medium, the coating fluid or dispersion which may

be formed in different aggregate conditions throughout the process. For example, this means that the temperature of the coating fluid does not change substantially on the path from a storage tank to an atomising unit. These constant conditions or temperature conditions could be disturbed, for example, if the spray head or the atomising unit is heated as a result of energy supplied when an ultrasonic spray head is used, for example. This heating could be transmitted to the coating fluid to be applied and could heat the coating fluid.

For example, it could transpire that the melting point of particles contained in a coating fluid is reached on the heated atomising unit. This could result in melting of the particles and sticking of the atomising unit or ultrasonic spray head. This would give rise to poor quality of the application or coating results.

It could also happen that a solvent present in a coating fluid evaporates prematurely, i.e. even before application. This premature evaporation, unless desired, could also result in poor quality of the application and coating results.

It may therefore be advantageous to set constant temperatures throughout the path or process of distribution of a gas or coating fluid.

An essentially constant temperature may be reached, for example, by cooling down an overheated area, e.g. an overheated atomising nozzle, by means of a temperature setting device, or for example by heating a supply line system, an air or gas supply, tubes, particularly capillary tubes or another distribution system for the coating fluid or for particles dissolved in a solvent. This heating could be necessary if the distribution system leads through a colder area. By cooling

the distribution system the conveyed coating fluid could also be cooled. The fluid, which is liquid under normal conditions, could therefore assume a viscous condition and obstruct transfer. Heating of the distribution system may also heat the conveyed medium or coating fluid indirectly, thereby influencing the temperature of the coating fluid. Direct influencing of the temperature of the coating fluid is also possible.

For example, a heating coil or a heat exchanger may be installed on the distribution system or may be flushed by the coating fluid, thereby also regulating the temperature, for example, by means of a control or regulating system, by either supplying or discharging heat. Heat supply via infrared systems or inductive systems is also possible.

In certain embodiments it is also advantageous, unlike keeping the temperature of the coating fluid constant, to provide different temperatures specifically at different points in the distribution system. Whilst in the case described above there is an interest in having as low a temperature gradient as possible, a temperature gradient is desirable in the latter case. This is advantageous, for example, in coatings, particularly coating fluids, or dispersions whose particles can be efficiently transferred in conjunction with a solvent.

In addition, it may be an advantage for coating, in certain embodiments, for the particles to be present in undissolved form, for which purpose the solvent must be removed. The increase in temperature, e.g. in an atomising unit according to the invention, particularly in a resonance body or a tube, allows the solvent to vaporise of evaporate so that the particles are present in undissolved form on the spray head or atomising unit or on the sound head.

The coating fluid can therefore be conveyed in this embodiment of the invention by a storage container as far as an atomising unit under temperatures which leave the particles dissolved in the solvent. This facilitates transfer. The increased temperature of the atomising unit then allows the solvent to vaporise in the region of the atomising unit or ultrasonic atomiser so that the particles transferred to the ultrasonic atomiser or sound head are present in undissolved form. They may therefore be applied more efficiently.

Other temperature gradients may in turn be advantageous for other applications, coating fluids or dispersions. These temperature gradients may be set by means of temperature setting devices and by means of a process temperature control device controlling the conditions that can be predetermined for a coating process.

Moreover, the temperature and coating characteristic of the coating fluid or spreading capacity of a coating fluid, or the droplets or particles formed by it, can also be preferably influenced according to the invention by adapting the temperature of an inert gas added in an air flow. This adaptation may be carried out directly or indirectly.

Furthermore, it may be preferable according to the invention to temper completely or partially a space or area around the substrate or, if necessary, the coating chamber correspondingly. For this purpose a hot spray mist, formed from atomised hot particles, can be mixed with a cooled inert gas or distributed in a cooled coating chamber, so that it cools, thereby improving the adhesivity of the particles on a substrate, for example. This may therefore influence the

temperature of the inertised air or the inertised gas, i.e. the mixture of coating fluid with inert gas or air.

The more temperature setting devices are installed distributed over the distribution system for the coating fluid or inert gas, the air or in the coating chamber, the more precisely temperature gradients can be adapted and the more flexibly conditions can be set for a coating process.

It is also possible, and preferable if necessary, to link the settings to a microprocessor, and therefore to store certain process samples and coordinate, preferably control, different temperature setting devices.

To obtain a spray pattern that is optimum for the application in question, the previously explained components which may contribute to varying the spray jet characteristic are controlled by means of a microprocessor. The volumetric flow of the coating fluid generated by the proportioning pump, as well as the working frequency and energy supply of the ultrasonic atomiser, is therefore controlled with a microprocessor. This microprocessor is also used for controlling the inert gas supply to the spray jet conditioning system, according to the flow rate. The individual factors which may influence the spray pattern may be set by the microprocessor and are dependent on each other.

Although the coating result for a substrate to be coated can be substantially improved solely with the ultrasonic atomiser according to the invention, as described above, this result, which is already satisfactory in itself, can be improved even further by retaining the substrate to be coated inside the spray mist with a substrate holder during the coating process in a position that is favourable for coating. Preferably this

substrate holder is suitable for subjecting the substrate retained in the substrate holder, in the region of the spray mist produced, to three different translatory and three different rotatory degrees of freedom of movement. In particular, the substrate can be moved with the substrate holder in the region of the spray mist in three different coordinate directions, thus enabling the substrate to be coated highly uniformly with coating fluid.

According to yet a further aspect of this invention, the coating result of a substrate that can be achieved with the high frequency atomising device according to the invention can be further improved in that, unlike coating methods of prior art, the substrate need not be removed from the substrate holder following the coating process for drying purposes, so that it can be hardened in a drying oven, but in that the high frequency atomising device itself comprises a drying device which is suitable for drying the spray mist coat formed on the substrate, or for hardening or cross-linking it. For instance, it is possible by means of this drying device to dry the same even during the coating process simultaneously with the application of the coating film.

This can be achieved, for example, by loading the freshly coated substrate with a heat flow even during the coating process. For this purpose the heat source may comprise, for example, a heating system which is in turn, just as the atomising unit, is enclosed by a heating housing open on one side, which has a controllable inert gas supply for generating a hot air flow. The inert gas fed to the heating housing is heated in the heating housing and escapes from it via a nozzle arranged on one of the openings of the heating housing, and can be fed specifically to the substrate by means of the nozzle.

Another possibility of drying the coating film formed on the substrate consists in first fully sealing the coating of the substrate, then moving the fully coated substrate, with the substrate holder, into the region of the escape opening of the heating housing nozzle, so that the drying or hardening of the coating film is carried out after the coating process.

Obviously it is also possible, instead of the drying based on thermal convection, to dry the coating film formed on the substrate indirectly by radiation, particularly infrared radiation. This drying by means of thermal radiation may prove particularly advantageous in that the heat source for generating the thermal radiation can be arranged outside the area of the high frequency atomising device where there is a risk of explosion. For example, the heat source for generating a thermal radiation may be arranged outside a housing in which are arranged the atomising unit and the positionable substrate holder in order to avoid cross flows that normally have a detrimental effect on an homogeneous spray pattern. This housing therefore protects the spray pattern generated with the atomising unit before any cross flow exerts a possible negative influence, so that the coating result and its quality can be improved still further by the housing, which surrounds at least the atomising unit and the positionable substrate holder.

A suction device which is suitable for collecting and sucking off the overspray, i.e. the quantity of atomised coating fluid which is sprayed past the substrate to be coated, can also be arranged in this housing, for example, to ensure that this overspray is not lost and can be fed back to the atomising unit, for example, for atomisation. Obviously this suction device, as well as the substrate holder, can also be

controlled by the above-mentioned microprocessor, so that the spray characteristic of the atomising device can also be influenced, for example, by manipulation of the suction flow and by generating a vacuum. On the other hand, by controlling the substrate holder by means of the microprocessor it is possible to retain the substrate to be coated constantly in an optimum position in the region of the spray jet produced, depending on all the other process parameters.

In addition freeze drying, vacuum drying or flow drying in the air or gas flow, by means of suitable drying devices in the arrangements described above, may be used instead of the above-mentioned heat drying processes. The person skilled in the art will in this case select the suitable drying device for each coating and drying task.

If drying, hardening or cross-linking are carried out within the scope of this invention, these operations are understood generally to involve the transition of the coating fluid from the liquid to the solid state, but the person skilled and experienced in the field of coating technology is able to deduce the exact significance of these possibilities which have been cumulatively summarised.

Emulsions, suspensions and/or solutions of solid or liquid substances in suitable solvents are considered as coating fluid. For example, solutions, suspensions, dispersions or emulsions of one or more active substances or active substance precursors in a suitable solvent may be atomised, but so may undiluted liquid active substances. In addition, solutions, emulsions and/or suspensions or dispersions of one or more polymeric or non-polymeric organic or inorganic substances, or any mixtures thereof, if necessary together with cross-linking agents, as well as reacting multicomponent compounds, can also

be atomised, the latter subject to the provision of a suitable drying/setting mechanism or an adequate pot life, to avoid setting inside the atomising device. Furthermore it is particularly preferable to use such coating materials, supplied from solutions, dispersions, suspensions or emulsions, which contain particles selected from polymeric, non-polymeric, organic or inorganic or mixed inorganic-organic or composite particles or any mixtures thereof. Preferred particles are micro- and nanoparticles. Examples of polymeric particles are PMMA, PLA, proteins, etc., examples of non-polymeric particles are metals, metal oxides, metal carbides, metal nitrides, metal oxynitrides, metal carbonitrides, metal oxycarbides, metal oxynitrides, metal oxycarbonitrides, metal hydrides, metal alkoxides, metal halogens, inorganic or organic metal salts. Also preferred are magnetic particles, examples of which are - without excluding others - iron, cobalt, nickel, manganese or mixtures thereof, for example iron-platinum mixtures, or as examples of magnetic metal oxides, iron oxide and ferrites. Examples of non-polymeric particles are also soot species and other nanomorphic carbon species, such as graphite, diamond, nanotubes, fullerenes and the like. Of particular preference are also particles which are supplied from sols and gels.

Melts of thermoplastic coating substances, e.g. tar, may also be used. In addition, the use of coating substances based on dyes and varnishes, organic polymers, duro- and thermoplastics, with fibre constituents such as cellulose, glass, stone or carbon fibres, and polymer fibres with organic and inorganic additives, and also catalysts, is also preferred according to the invention. Usable and suitable coating substances within the scope of this invention are disclosed in DE 103 24 415, in the section headed "Polymer Films", and are therefore fully incorporated in this disclosure.

The term "active substances" is also understood to include, according to the invention, pharmacologically active substances such as drugs, medicinal products, pharmaceutical products, but also microorganisms, living organic cell material, enzymes and also biocompatible inorganic or organic substances. The term "active substance precursor" refers to substances or mixtures of substances which are converted to active substances of the type mentioned above after application on an implant to be coated by means of thermal, mechanical, chemical or biological processes.

Molten active substances, or active substances dissolved, suspended or dispersed in melts, may be applied by the device according to the invention, as well as those which are present in special forms of supply that can be suspended, dispersed or emulsified, for example active substances encapsulated in polymers. In one specific embodiment the distribution of the coating solution or of components of the coating solution, and in particular embodiments also the geometrical orientation, e.g. of particles with magnetic properties or conductive properties, is specifically influenced by the anode and pole plate system based on magnetic or dielectric principles of action, in which case the anode and pole plate system is designed with one or more channels and its spatial alignment can be varied.

Furthermore, the electrode or electrostatic system, with associated activation electronics and energy supply, may form an integral part of the device, in a preferred embodiment, so that it specifically influences the distribution, charging, alignment and morphology of coating solutions or their constituents with variable magnetic and ionisation fields.

Particles, particularly movable or flying particles or droplets, are influenced by the crossing of electrical or magnetic fields. In preferred embodiments according to the invention they are electrically charged or ionised as they cross electrical or magnetic fields provided for this purpose, or are otherwise influenced by an interaction. For example, the mutual alignment of particles may vary. A variation of alignment is caused by the magnetic field, particularly in the case of ferrite-containing particles particularly preferred according to the invention.

Variations in the mutual alignment of the particles to be applied, according to the invention, or ionisation of the particles or electrical charging, give rise to an extremely uniform distribution of a coating film or a coating fluid. Particles orientated in this manner, particularly nanoparticles, have better adhesion to a substrate. Moreover, the drying process according to the invention is accelerated and improved by the uniform alignment and influencing of the morphology.

It is therefore advantageous to influence coating fluids, particularly spray mists or droplets formed from them, by means of electrical or magnetic fields, which are preferred according to the invention. The fields here may be electro- or magnetostatic fields or time-variant fields modulated with frequency patterns.

The influencing of the electrical or magnetic fields preferred according to the invention may take place during the flight of the particles or the spray mist, but it may also take place during or after deposition on the substrate. The influencing of the electrical or magnetic fields may take place simultaneously or staggered in time. Moreover, a multi-channel

influence, i.e. an influence caused by a plurality of devices to be provided according to the invention for generating electrical or magnetic fields, and one which can also act in different spatial planes, is particularly preferable in certain embodiments.

For this purpose electrical fields can be generated by means of electrode, anode or pole plate systems suitably arranged in the device according to the invention. These may, if necessary, be supplied with high voltage (HV). The course of the fields and their intensity may be influenced by the shape of the electrodes.

Magnetic fields may, for example, be generated by means of electro- or permanent magnets suitably arranged in the device according to the invention, and in the case of the magnetic fields too, the intensity and course of the fields are influenced by the shape of the magnets.

It is advantageous not merely to generate electro or magnetostatic fields. The activation and modulation of the fields preferred according to the invention with certain frequency patterns, or a time variation in the intensity, can influence the wetting behaviour of the coating fluid and the way in which the spray mist is deposited on the substrate.

The system preferred according to the invention for generating a continuous or time-variant magnetic field consists of a magnet, preferably an electromagnet that can be modulated in frequency and amplitudes by means of microprocessor control, which magnet is provided with pole shoes advantageously arranged geometrically. Furthermore, the entire arrangement can be spatially varied by microprocessor control in relation to the substrate to be coated. The system for generating a

modulable LF-HF field consists essentially of a microprocessor control for generating frequency and amplitude samples and two or more electrodes, which may be aligned axially or radially so that they are spatially variable, according to the application.

Suitable solvents for coating fluids, in the form of solutions, suspensions or emulsions, include, for example, alcohols and/or ethers and/or hydrocarbons such as methanol, ethanol, n-propanol, isopropanol, butoxydiglycol, butoxyethanol, butoxyisopropanol, butyoxypropanol, n-butyl-alcohol, t-butyl-alcohol, butylenes glycol, butyl octanol, diethylene glycol, dimethoxydiglycol, dimethyl ether, dipropylene glycol, ethoxydiglycol, ethoxyethanol, ethylhexane diol, glycol, hexane diol, 1,2,6-hexane triol, hexyl alcohol, hexylene glycol, isobutoxypropanol, isopentyl diol, 3-methoxybutanol, methoxydiglycol, methoxyethanol, methoxyisopropanol, methoxymethyl butanol, methoxy PEG-10, methylal, methyl-hexyl ether, methylpropane diol, neopentyl glycol, PEG-4, PEG-6, PEG-7, PEG-7, PEG-9, PEG-6-methylether, pentylene glycol, PPG-7, PPG-2-buteth-3, PPG-2 butyl ether, PPG-3 butyl ether, PPG-2 methyl ether, PPG-3 methyl ether, PPG-2 propyl ether, propane diol, propylene glycol, propylene glycol-butyl ether, propylene glycol-propyl ether, tetrahydrofuran, trimethylhexanol, phenol, benzol, toluene, xylol; and also water, if necessary in a mixture with dispersion aids, as well as mixtures of the above.

With the device according to the invention the surface of the object to be coated can be partially or, essentially, fully coated or even coated many times. Multiple coating is carried out by the multiple use of the atomising device in separate process steps, and if necessary drying steps may be applied after each coating process.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of this invention are described in greater detail in the following, with reference to the attached drawings, for a better understanding and for further explanation of the invention. The person skilled in the art is aware in this case that all the features described in the following can be applied and generalised, within the field of this invention, for all embodiments described and conceivable, as well as their combinations.

Fig. 1 is a schematised system sketch of the high frequency atomising device according to the invention;

Fig. 2 shows a section through the resonance body according to the invention, which widens into the shape of a trumpet;

Fig. 3 is a schematised system sketch of a preferred embodiment of the high frequency atomising device according to the invention, with temperature setting devices and devices for generating electrical and magnetic fields.

In the figures the same parts are identified with corresponding reference symbols.

Fig. 1 shows an exemplary embodiment of the high frequency atomising device according to the invention in a schematised representation. As may be deduced from Fig. 1, the high frequency atomising device shown schematically in it comprises, among other things, an atomising unit 1, which is suitable for atomising a coating fluid fed to it. Atomising

unit 1 may, for example, be an ultrasonic atomiser which can be excited, for example, with a piezoelectric element to generate high frequency vibrations. Atomising unit 1 can be loaded with a precision proportioning pump 4 with a coating fluid which is retained in a storage tank 5 for storing the coating fluid. As may be deduced from Fig. 1, the coating fluid is pumped from storage tank 5 with precision pump 4 via a system of tubes to atomising unit 1. The coating fluid fed in this way to atomising unit 1 is excited by atomising unit 1 to generate high frequency vibrations and is conveyed further in the direction of resonance body 2 by the continuous volumetric flow generated by precision proportioning pump 4 via capillary tube 17. Instead of exciting the coating fluid directly by means of the atomising unit to generate vibrations as the fluid passes it, it is obviously also possible to excite only resonance body 2, which in turn then excites the coating fluid to generate vibrations as soon as it has reached resonance body 2.

Resonance body 2, including capillary tube 17, is shown in Fig. 2 on an enlarged scale. As may be deduced from Fig. 2, capillary tube 17 is incorporated in the resonance body denoted by the reference number 2, so that no discontinuities or jumps are produced in the transition between the end of capillary tube 17 and the expanding inner face 4 of resonance body 2. The coating material excited to generate high frequency vibrations by means of atomising unit 1 is fed via capillary tube 17 to resonance body 2, and is then distributed on the inner face of horn 18 of resonance body 2 in a thin coat, and is then further dispersed on perforated disc 22, as indicated by the arrows, which horn widens into the shape of a trumpet.

Resonance body 2, which in turn is also excited to generate high frequency vibrations, reinforces the vibrations induced into the coating fluid, causing concentric capillary waves to be formed in the coating fluid, which is distributed on horn 18 that widens into the shape of a trumpet. Because of the inertia of the mass of the coating fluid excited to generate capillary waves, very fine droplets of the coating fluid separate from the vibration curves of the capillary waves, giving rise to the formation of a spray mist.

In addition to the advantageous embodiment of resonance body 2, with horn 18 that widens into the shape of a trumpet, the transition between the feed line to the atomising tip and the surface thereof, disclosed in US 4,655,393, is also indicated as a comparison in Fig. 2 by a dotted line and identified by the reference number 19. As can be deduced from this, the transition between the feed line and the surface of the atomising tip has a discontinuity in the form of an edge, which prevents the coating fluid from being dispersed uniformly on the surface of the atomising tip. This in turn causes coarser drops to become detached from the edge-like transition, in uncontrolled fashion, resulting in the impairment of the coating result already explained. However, counteracting this risk of impairment of the coating result due to detachment of larger droplets was, among other things, an object of this invention, an object which is achieved, among other things, by the continuously expanding horn shape of resonance body 2 shown in Fig. 2.

As may further be deduced from Fig. 1, atomising unit 1 may be surrounded by a housing 16 open on one side. Resonance body 2 is arranged in one of the openings of housing 16. Air nozzle/gas nozzle/inert gas nozzle 3 connects directly to one of the openings of housing 16 in the form of an expanding

funnel, so that an annular gap is formed between the atomiser plate of resonance body 2 and the expanding funnel of inert gas nozzle 3. Housing 16, in which atomising unit 1 is arranged, is supplied with a controllable inert gas volumetric flow, whose volume is set by means of control valve 12, which is controlled, for example, by microprocessor 7. In the preferred case microprocessor 7 also controls the operating frequency of atomising unit 1 and the volumetric flow of precision proportioning pump 4, which supplies atomising unit 1 with coating means from tank 5.

The inert gas with which the interior of housing 16 is loaded is dispersed in housing 16 and escapes from one of the openings of housing 16 through the annular gap which is formed between the atomiser plate of resonance body 2 and the expanding funnel of inert gas 3. As a result of this escape of inert gas from housing 16, the spray mist which has separated from resonance body 2 excited to generate high frequency vibrations can be modulated in hits spray pattern. The spray pattern can be varied in different ways, particularly in conjunction with inert gas nozzle 3 and the inert gas escaping through the annular gap. For example, the volumetric flow of the spray jet can be accelerated by varying the inert gas flow, or the spray jet can be widened or reduced by varying the opening angle of the funnel of inert gas nozzle 3.

Substrate 14 can be positioned by substrate holder 8, by means of the workpiece clamping device 9 belonging to the substrate holder, underneath resonance body 2 of the high frequency atomising device according to the invention. As denoted here by the references x, y, z and r, substrate holder 8 is able to subject substrate 14 to three different translatory movement directions x, y and z, and one rotatory movement r. Substrate 14 can therefore be retained and moved constantly in a

suitable position inside the spray mist by means of substrate holder 8 throughout the coating process. For monitoring the present position of substrate 14 and to vary the position of substrate 14 within the spray mist, substrate holder 8 is controlled by microprocessor 7, for example, with which all the processes and parameters of the device according to the invention are monitored.

In the region inside substrate 14 a controllable vacuum suction system 10 can be arranged for further spray jet conditioning and for sucking off the overspray, the associated suction pump of which system is also controlled by microprocessor 7.

The high frequency atomising device according to the invention, shown in Fig. 1, also comprises a drying device 6, e.g. a heat source, which is arranged to dry or harden the freshly coated substrate 14. Drying device 6 comprises, for example, a heating system that is preferably controllable by microprocessor 7, which system is accommodated in a housing 20 open on one side. The interior of housing 20 open on one side, as housing 16 of atomising unit 1, is loaded with an adjustable inert gas volumetric flow which is set by means of control valve 13. Control valve 13 may in turn be controlled by microprocessor 7 as a function of all the process parameters. The inert gas volumetric flow fed to this housing 20 is heated in housing 20 by the heat from heat source 6, and escapes through the opening in housing 20 formed by nozzle 21. With the heat flow thus generated the freshly coated substrate 14 can be dried, but for this purpose it would have to be moved from the position shown in Figure 1 in the direction of heat source 6. However, it is also possible to align nozzle 21 of heat source 6 so that the film coats freshly coated on

substrate 14 are dried immediately after their application to substrate 14, e.g. in the position shown in Fig. 1.

In order to protect the coating process from possible cross flows or dust, atomising unit 1, including housing 16 surrounding it, drying device 6, vacuum suction system 10 and of course substrate 14 itself, can be arranged in housing 11, represented schematically here by dotted lines. If instead of a drying device 6 based on drying flow, a heat source 6 based on thermal radiation were to be used, such a drying device 6 based on thermal radiation could of course also be arranged outside housing 11 in order to dry the freshly coated substrate in housing 11. In any case it is not necessary to remove substrate 14 from workpiece clamping device 9 of substrate holder 8 in order to dry substrate 14 after coating due to the use of drying device 6, thus avoiding possible damage to the coating of substrate 14 not yet dried when it is removed from workpiece clamping device 9.

The device according to the invention may be adapted in certain embodiments for extensive coating of substrates by providing a multiplicity of atomisers in cascade fashion and guiding the substrates along them on conveying devices, or by guiding an atomiser cascade along the substrates on a conveying device. Suitable conveying devices include, for example, conveyor belts and the like.

Fig. 3 is based essentially on the high frequency atomising devices shown in Fig. 1. Unlike Fig. 1, Fig. 3 also shows a process temperature control device 27 with connected first 23, 25, second 24 and third 26 temperature setting device. Process temperature control device 27 is connected to microprocessor 7 and can receive settings or instructions for settings from this microprocessor for conditions for a coating process. For

example, temperature gradients of a coating fluid may therefore be produced or compensated for in a storage tank 5 and on an atomising unit 1. Whether a temperature gradient is required or is to be prevented depends on the material used as coating fluid or its thermal characteristic. This enables the behaviour of the coating fluid during transport or spraying to be suitably influenced.

The temperature of the coating fluid in storage tank 5 may be set by means of first temperature setting device 23. As the further first 25, second 24 and third 26 temperature setting device, this is represented as a heating soil. However, this is also understood to include other heat sources, such as infrared radiators, heat exchangers, heat pumps etc. Moreover, all the temperature setting devices can also be used to extract heat and for cooling, in which case cooling units or fans can be used, for example.

Whilst two first temperature setting devices 23, 25 for influencing the temperature of the coating fluid are shown in Fig. 3, any number of first temperature setting devices may be arranged along the distribution system of the coating fluid, according to requirements. The distribution system comprises essentially storage tank 5, precision pump 4, atomising unit 1 and a tube system which connects storage tank 5 to precision pump 4, and precision pump 4 to atomising unit 1. In particular, capillary tube 17 and resonance body 2 are also incorporated. Each of these elements of the distribution system can be provided separately with a first temperature setting device. The action of the temperature setting devices can be exerted directly, i.e. directly on the coating fluid. An example of direct action of first temperature setting device 23 on the coasting fluid is shown in Fig. 3 in storage tank 5.

A temperature setting device, e.g. first temperature setting device 25, acts indirectly on the tube between precision pump 4 and atomising unit 1. By varying the temperature of the tube the temperature of the coating fluid flowing through the tube is influenced indirectly.

Besides the influencing the temperature of the coating fluid by first temperature setting devices 23 and 25, the temperature of the inert gas in inert gas feed line 31 can be set by means of second temperature setting device 24. Since the tempered inert gas interacts with the spray mist whilst it is escaping from inert gas nozzle 3 and modulates the spray pattern of the spray mist, the temperature of the spray mist which has separated from the resonance body can also be adapted.

The temperature prevailing in coating chamber 32 also has an influence on the dispersion behaviour and coating behaviour of the spray mist on the substrate. This temperature may also determine the behaviour of the coating when it is being dried. Moreover, the thickness of the coating, particularly the coating film, on the substrate, can be influenced by the temperature prevailing in coating chamber 32.

Fig. 3 also shows a device 29 for generating an electrical field. This has two electrodes which are connected to a high voltage generator 28 (HV). Between the electrodes an electrical field can be generated in the region between atomising unit 1 and substrate holder 9 and the substrate when a suitable voltage is applied. In this case the substrate and, if applicable, also at least part of substrate holder 9, lie fully in the electrical field, so that the field acts on the spray mist when the sprayed particles adhere to the substrate.

Whilst the figure shows a single-channel structure of the device for generating an electrical field, a multi-channel structure is also possible. In the case of a multi-channel structure a plurality of devices 29 are provided for generating an electrical field, each of which is separately activated by HV generator 28.

HV generator 28 has a connection to microprocessor 7 by which it can be controlled by the microprocessor. In addition to electrostatic fields, time-variable electrical fields, with an intensity variable over time or different frequency patterns, can therefore also be realised.

Similarly to the electrical field, a magnetic field can be generated with device 30 for generating a magnetic field between atomising device 1 and substrate holder 9, with substrate. This may be magnetostatic, i.e. constant or time-variant, i.e. variable over time. The modulation is carried out here by the LF/HF generator, which is connected to the microprocessor, from which the LF/H generator receives control signals.

A single-channel structure is also shown for the magnetic field, although a multi-channel structure is possible.

The magnetic field can be generated by means of a permanent magnet or electromagnet. Fig. 3 shows an electromagnet. A U-shaped core, e.g. a ferrite core, is surrounded by an electrical coil on the underside of the magnet, which is the side opposite resonance body 2. Excited by the current flow generated by the LF/HF generator in the coil, magnetic field lines are formed between the parallel flanges of the core, which field lines pass through the space between the flanges

with a magnetic field. The space between atomising unit 1 and the substrate, and if necessary at least parts of substrate holder 9, is therefore also passed through with a magnetic field. This magnetic field influences the spray mist to be moved onto the substrate.

Both device 29 for generating an electrical field and device 30 for generating a magnetic field, at least parts thereof, may be located either inside housing 11, i.e. in coating chamber 32 or outside of it. If a suitable material is selected for housing 11, the electrical and magnetic fields may exert their actions in housing 11, i.e. from outside into coating chamber 32.

If device 29 for generating an electrical field, as well as device 30 for generating a magnetic field, are located fully outside housing 11, this may be advantageous in terms of contamination of these elements.